Form 9-1366
(April 2015)

U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

JOINT FUNDING AGREEMENT

Customer #:	6000001225
Agreement #:	18ESFL000000111
Project #:	MC00E2J
TIN #:	59-6000531
Fixed Cost Agreement	YES

FOR

AN INVESTIGATION OF WATER RESOURCES

THIS AGREEMENT is entered into as of the, 12 day of June, 2018 by the U.S. GEOLOGICAL SURVEY, UNITED STATES DEPARTMENT OF THE INTERIOR, party of the first part, and the BROWARD COUNTY, party of the second part.

1. The parties hereto agree that subject to availability of appropriations and in accordance with their respective authorities there shall be maintained in cooperation AN EVALUATION OF DRAINAGE INFRASTRUCTURE CAPACITY UNDER PROJECTED SEA-LEVEL AND CLIMATE CONDITIONS, BROWARD COUNTY, FLORIDA herein called the program. The USGS legal authority is 43 USC 36C; 43 USC 50; and 43 USC 50b.

2. The following amounts shall be contributed to cover all of the cost of the necessary field and analytical work directly related to this program. 2(b) includes In-Kind Services in the amount of $0.00 .

   (a) by the party of the first part during the period

Amount	Date	to	Date
$318,000.00	June 12, 2018		June 11, 2021

   (b) by the party of the second part during the period

Amount	Date	to	Date
$470,000.00	June 12, 2018		June 11, 2021

   (c) Contributions are provided by the party of the first part through other USGS regional or national programs, in the amount of: $0.00

   Description of the USGS regional/national program:

   (d) Additional or reduced amounts by each party during the above period or succeeding periods as may be determined by mutual agreement and set forth in an exchange of letters between the parties.

   (e) The performance period may be changed by mutual agreement and set forth in an exchange of letters between the parties.

3. The costs of this program may be paid by either party in conformity with the laws and regulations respectively governing each party.

4. The field and analytical work pertaining to this program shall be under the direction of or subject to periodic review by an authorized representative of the party of the first part.

5. The areas to be included in the program shall be determined by mutual agreement between the parties hereto or their authorized representatives. The methods employed in the field and office shall be those adopted by the party of the first part to insure the required standards of accuracy subject to modification by mutual agreement.

6. During the course of this program, all field and analytical work of either party pertaining to this program shall be open to the inspection of the other party, and if the work is not being carried on in a mutually satisfactory manner, either party may terminate this agreement upon 60 days written notice to the other party.

9-1366 (Continuation) Customer #: 6000001225 Agreement #: 18ESFL000000111

7. The original records resulting from this program will be deposited in the office of origin of those records. Upon request, copies of the original records will be provided to the office of the other party.

8. The maps, records, or reports resulting from this program shall be made available to the public as promptly as possible. The maps, records, or reports normally will be published by the party of the first part. However, the party of the second part reserves the right to publish the results of this program and, if already published by the party of the first part shall, upon request, be furnished by the party of the first part, at costs, impressions suitable for purposes of reproduction similar to that for which the original copy was prepared. The maps, records, or reports published by either party shall contain a statement of the cooperative relations between the parties.

9. USGS will issue billings utilizing Department of the Interior Bill for Collection (form DI-1040). Billing documents are to be rendered QUARTERLY. Payments of bills are due within 60 days after the billing date. If not paid by the due date, interest will be charged at the current Treasury rate for each 30 day period, or portion thereof, that the payment is delayed beyond the due date. (31 USC 3717; Comptroller General File B-212222, August 23, 1983).

	U.S. Geological Survey United States Department of the Interior		BROWARD COUNTY
	USGS Point of Contact		Customer Point of Contact
Name:	Mrs. Susan Jones	Name:	Ms. Ana Carolina Coelho Maran, Ph.D.
Address:	4446 Pet Lane, Suite 108 Lutz, FL 33559 DUNS #: 137783937/TAS: 148/90804	Address:	115 S. Andrews Ave., Room 329-H Fort Lauderdale, FL 33301
Telephone:	813.498.5009	Telephone:	954.519.0365
Email:	swjones@usgs.gov	Email:	

Signatures and Date

Signature:	Date: 5-21-18	Signature:	Date:
Name:	David M. Sumner, Ph.D.	Name:	
Title:	Director, CFWSC	Title:	
Signature:	Date:	Signature:	Date:
Name:		Name:	
Title:		Title:	
Signature:	Date:	Signature:	Date:
Name:		Name:	
Title:		Title:	

Reviewed and approved as to form
Andrew J. Meyers, County Attorney

By: _____
Joseph K. Jarone, Assistant County Attorney

By: _____ 5/22/18
Maite Azcoitia, Deputy County Attorney

Title: Evaluation of Drainage Infrastructure Capacity under Projected Sea-Level and Climate Conditions, Broward County, Florida

1. Executive Summary:

The primary objective of this study is to characterize the drainage capacity and potential for inundation of the urbanized areas of Broward County, Florida under projected climate conditions and rising sea-level. The United States Geological Survey ("USGS"), a bureau of the United States Department of the Interior, will develop a groundwater/surface water model based on existing models and will expand the dynamic representation of the surface water system throughout the County. Existing models will provide the necessary hydraulic parameters. Best available information about the surface water system will be incorporated within the model and additional information may be requested from a variety of sources as required. Model parameters will be adjusted to improve ability of the model to replicate historical conditions, but a rigorous, formal recalibration is not planned. An analysis of the model sensitivity to uncertainties – hydraulic parameters and stresses – will be conducted followed by simulation of future scenarios of climate, sea level, and water management.

Future scenarios will be developed using projected climate and sea-level rise estimates. Simulated output (e.g., water levels, areas of inundation, and system flows) will be used to evaluate the response to these projections; outputs could be used to evaluate possible adaptation or mitigation strategies. USGS will produce a USGS report or journal article documenting the development of the flow model and study results. USGS will release a flow model and model archive to Broward County (the "Cooperator") and the public as a USGS Data Release.

USGS will develop the model, and USGS and the Cooperator will jointly fund the development of the model. However, the continuation of this Agreement beyond the end of any Broward County fiscal year and the Cooperator's contribution to the development of the model is subject to both the appropriation and the availability of funds in accordance with Chapter 129, Florida Statutes.

2. Background and Problem Statement:

In coastal Broward County, Florida, rising sea-level has been empirically observed over the last decade, with increasingly frequent tidal inundation in lower-lying areas and increasing high-water elevations. The low altitude, flat topography, and high permeability of the surficial aquifer system, combined with rising sea level, result in decreasing drainage potential, particularly during substantial precipitation events. Understanding and mitigating the consequent risk to residents, businesses, and critical infrastructure are high priorities for County managers and planners. The County needs to be able to identify areas of greatest risk, test management or adaptive actions, and project timelines for implementation of such actions.

A previous study (Decker and others, in preparation) tested a novel approach to simulating surface water/ groundwater interactions in the urban hydrologic environment, and applied the approach to evaluate the effects of sea-level rise and changes in precipitation on the operations of several primary control structures, and to assess the potential for inundation in selected area. The study focused on the east-central part of the County. Outcomes from the study can be applied to other parts of the County, where controls on drainage differ. For example, the northern part of the County has a substantially higher topographic gradient, and control structures are closer to the coast than in the central and southern parts of the County. The southern part of the County is generally characterized by less direct drainage to the Atlantic Ocean than the central and northern parts of the County, and by very low altitude near the Everglades. Furthermore, new drainage control structures and operations may be implemented that will affect drainage in parts of the County.

To address the need to identify areas at risk of inundation, particularly in the central and southern parts of the County, and to evaluate the effects of proposed drainage management actions, the USGS, in cooperation with Broward County Environmental Planning and Community Resilience Division, proposes to characterize drainage capacity and potential for inundation throughout the urbanized areas of Broward County for a variety of hydrologic conditions. Questions of interest include:

- What are the effects of loss of drainage capacity with sea-level rise and changes in climatic patterns and which areas within the County are most vulnerable?
- How will proposed operations at drainage structures such as S-9 be affected by sea level rise and changes in climatic patterns?
- How will the C-11 impoundment project or other proposed water management activities affect drainage and inundation potential in the urbanized areas of the County?

3. Objectives and Scope:

To characterize drainage capacity and the potential for inundation, USGS will develop a model to simulate the historical water levels and drainage system flows throughout the urbanized areas of Broward County, Florida. The proposed model expands upon models previously developed by Decker and others (in preparation), Hughes and others (2016), and Langevin and Zygnerski (2013). The model will account for surface water drainage, including flows through control structures, groundwater flow, and groundwater/surface water interaction to simulate groundwater levels and surface water levels. The model will be used to evaluate how groundwater levels and the surface water system respond to changes in sea level and climate based on projected scenarios. The model will also be used to evaluate strategies to reduce the possible adverse effects of climate change and sea level rise on drainage and on shallow subsurface storage in the study area.

Application of the model to address inundation potential in Broward County may also provide opportunities to advance techniques in modeling of this type of urban drainage system or to create a more versatile and robust tool for evaluating the system and the effects of potential changes on the system. Improved modeling approaches that have been successfully used or may be tried include:

- using a level-pool approach for drainage control areas;
- using algebraic algorithms instead of more computationally intensive solutions;
- minimizing use of overland flow component of solutions to where it is most needed;
- testing optimal grid-refinement for addressing problems at scales of interest for County, while keeping computational times reasonable for application simulations;
- focusing projections on simulations of short duration (e.g. seasonal, monthly, design-storm events).

This project may also present an opportunity to incorporate the latest research on projected climate conditions for southeast Florida for any hydrologic predictions. Current USGS research is evaluating a suite of projected future downscaled climate models for the southern Florida peninsula, and the associated uncertainty, at various temporal scales, with a particular emphasis on precipitation projections and reduction of uncertainty. Results from this research may be available within the timelines needed for the proposed study.

4. Approach:

To achieve the project objectives, USGS will develop a three-dimensional groundwater flow model for northern, central, and southern Broward County based on existing groundwater models. The proposed model will expand the spatial extent of the county-scale model developed by Decker and others (in preparation), which is based on the saltwater intrusion model of central and southern Broward County developed by Hughes and others (2016). The northern expansion will use information from the saltwater intrusion model of northern Broward County developed by Langevin and Zygnerski (2013), which is currently being used by Broward County for future scenario modeling. Any available modifications, improvements, or newly calibrated parameters will be incorporated. The proposed modeling strategy will use MODFLOW 2005 (Harbaugh, 2005) to model the groundwater system, which is based on Darcy's Law and requires that model properties be assigned using the assumption of an equivalent porous medium.

The proposed modeling strategy uses a combination of the SWR1 (Hughes and others, 2012) and URO processes (Decker and Hughes, 2013) to model the surface water system similar to Decker and others (in preparation). Other packages may be used to represent processes within the surface water system, if needed, including the UZF (Niswonger and others, 2006), EVT, RCH, and RIV (Harbaugh, 2005) packages. Decker and others (2017) used SWR1 to dynamically simulate a portion of the canal system in

central Broward County. That methodology would be refined and expanded to the other areas of the County. The SWR1 process is a surface water routing process that simulates one- or two-dimensional routing of surface water. Surface water can be routed using a diffusive wave approximation or a level-pool approach of cascading pools separated by specified structure geometry or operations. Surface water control structures simulated may include fixed-crest weirs, gated spillways, or stage-discharge relations to represent the operational characteristics of the system. The URO process would be used to simulate rainfall, evapotranspiration, infiltration, recharge, and possible routing to SWR1 where needed. URO uses a conceptualized, water-content dependent approximation of infiltration and recharge.

A significant limitation to the development of the model and the reliability of the results is the lack of information about the drainage system, particularly in the northern and southern parts of the County. Of particular value are drainage canal locations, depths, and interconnectivity. To address these data gaps, USGS will request additional information from a variety of sources (for example, drainage districts and municipalities), and/or limited field verification may be required. Remaining unknown parameters, geometry, or feature connections will have to be estimated using best available information.

Existing models will provide hydraulic parameters for the model developed for this project. These include calibrated groundwater flow parameter values from the central and southern saltwater intrusion model (Hughes and others, 2016), and the northern saltwater intrusion model (Langevin and Zygnerski, 2013). If newer or refined parameter information exists or becomes available, it may be incorporated. Groundwater parameters may be altered in order to improve model performance or fit to historical conditions, but rigorous recalibration will not be a primary focus of this project. Surface water system flow parameters used by the inundation model (Decker and others, in preparation) will be used for the southern and central parts of the County, while new parameters will be developed for the northern part using similar methods.

Once USGS constructs the model and adequately tests it, USGS will perform a sensitivity analysis. Climatic, meteorological and hydrologic stresses, as well as surface water and groundwater model parameters, will be varied to evaluate the model response and help distinguish factors that substantially influence the simulated results. Assuming the model will be able to adequately represent the behavior of the surface water system under historical conditions, it will then be used to simulate the same system under differing climatic, meteorological, sea level or operational conditions. The results could be used to evaluate the system's response to projected future scenarios and then used to evaluate possible adaptation or mitigation strategies.

Specific water management actions or adaptation strategies tested may include changes to existing structure operations or target water-levels, representation of drains or pumps in specific areas of concern, and changes to network routing or operations based on proposed system changes. A minimum number of two such scenarios will be tested in order to evaluate the model's ability to simulate these types of changes to

the surface water representation. USGS project personnel will work with the Cooperator to formulate a set of finalized scenarios to be tested.

5. Information Products

1) USGS Data Release of flow model and archive
2) USGS report or journal article documenting flow model and model results

6. References

Decker, J.D., Hughes, J.D., 2013, Urban Runoff (URO) Process for MODFLOW 2005: Simulation of Sub-Grid Scale Urban Hydrologic Processes in Broward County, Florida, Paper presented at MODFLOW and More 2013: Translating Science into Practice, Integrated Groundwater Modeling Center, Colorado School of Mines, Golden, CO, p. 216-221

Decker, J.D., Hughes, J.D, and Swain, E.D., in preparation, Potential for Increased Inundation in Flood Prone Regions of South Florida in Response to Climate and Sea-Level Changes in Broward County, FL, 2060-2069: United States Geological Survey Scientific Investigations Report, 201x-xxxx, x p.

Harbaugh, A.W., 2005, MODFLOW-2005, The U.S. Geological Survey modular ground-water model—the Ground-Water Flow Process: U.S. Geological Survey Techniques and Methods 6-A16, variously p.

Hughes, J.D., Langevin, C.D., Chartier, K.L., and White, J.T., 2012, Documentation of the Surface-Water Routing (SWR1) Process for modeling surface-water flow with the U.S. Geological Survey Modular Ground-Water Model (MODFLOW-2005): U.S. Geological Survey Techniques and Methods, book 6, chap. A40 (Version 1.0), 113 p. Available online at http://pubs.usgs.gov/tm/6a40/

Hughes, J.D., Sifuentes, D.F., and White, J.T., 2016, Potential effects of alterations to the hydrologic system on the distribution of salinity in the Biscayne aquifer in Broward County, Florida: U.S. Geological Survey Scientific Investigations Report 2016–5022, 114 p., http://dx.doi.org/10.3133/sir20165022.

Langevin, C.D. and Zygnerski, Michael, 2013, Effect of sea-level rise on salt water intrusion near a coastal well field in southeastern Florida: Groundwater vol. 51, no. 5, p. 781-803, http://onlinelibrary.wiley.com/doi/10.1111/j.1745-6584.2012.01008.x/full.

Niswonger, R.G., Prudic, D.E., and Regan, R.S., 2006, Documentation of the Unsaturated-Zone Flow (UZF1) Package for modeling unsaturated flow between the land surface and the water table with MODFLOW-2005: U.S. Geological Survey Techniques and Methods 6-A19, 62 p.

7. Project Schedule:

Estimated start date (subject to change): June 12, 2018
End Date: June 11, 2021, or 3 years after start date

	Year 1	Year 2	Year 3
Data compilation	X		
Model construction	X	X	
Scenario simulations		X	
documentation			X

8. Budget Summary:

Table 1. Task 1 Costs – distribution based on estimated start date, subject to change

	Project Year 1	**Project Year 2**	**Project Year 3**	**Project Total**
Total Project Costs	**$ 250,000**	**$ 324,000**	**$ 214,000**	**$ 788,000**
Cooperator Funding	$ 180,000	$ 180,000	$ 110,000	$ 470,000
USGS cost share	$ 70,000	$ 144,000	$ 104,000	$ 318,000